

Innovative Packaging Interim Oral Presentation

11/17/08

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Agenda

- Introduction
- Study Approach
- Topical presentations
- Discussion
- Next Steps
- Conclusion

Introduction

- NASA solicited a study to identify means to reduce overhead in mass and volume for exploration packaging
- OSS proposed a broad-reaching study of how packaging can be optimized to most effectively support the Constellation mission
- GOAL: Identify high-leverage recommendations for packaging which will have sustained value when embedded in the Cx architecture
- Sustainability was identified as a principal concern
 - Program sustainability: To what extent can effective packaging solutions contribute to the stability and growth of the Constellation program
 - Technical sustainability: To what extent can effective packaging simplify and streamline operations, improve mass and volumetric efficiency, and promote successful exploration using a technically sustainable architecture

Approach

- Top-down approach:
 - Working from the overall systemic constraints of the architecture, explore packaging requirements, performance and design characteristics which typify effective solutions
 - Identify design and operational considerations that influence packages, mission operations and hosting element designs
- Bottom-up approach:
 - Working from the perspective of the contents of packaging, explore packaging characteristics that effectively meet contents-related requirements
 - Identify design and operational considerations for contents that influence packaging configurations
- Exploration of Analogs
 - Identify analogous applications where effective packaging has improved performance
- Specific topical studies
 - Identify and explore in greater detail specific packaging applications and performance factors

Topical Presentations

- Topical Presentations are provided for each submitted document in the order in which the documents were assembled for delivery:
 - 1. Alternative Packaging Mid-term Study Report
 - 2. Proportions
 - 3. Barrier Free Environment
 - 4. Lifecycle Analysis
 - 5. Food and Waste Packaging
 - 6. Metrics
 - 7. Analogs
 - 8. Energy Packaging
 - 9. Lunar Sample Return Packaging
 - 10. Architectural Simulations

Alternative Packaging Mid-term Study Report

- This document covers the entire scope of the study from the PI's perspective
- It explores a wide range of packaging development and effectiveness considerations
- It provides context for the other more detailed study topics

Overall Study Report: highlights

- Packaging effectiveness is subject to many figures of merit (see next chart)
- Packaging development must recognize human performance in terrestrial, in-transit, and lunar environments
- Recognition of robotic operability in packaging development may return real advantages
- Packaging absorbs many limited resources
- Packaging materials offer potential resources of value to in-situ operations
- Coordinating packaging of portable equipment and of systems according to a common set of requirements fosters a more effective architecture

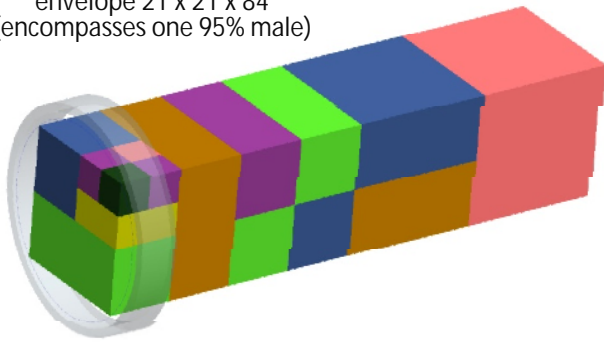
Overall Study Report: highlights (cont.)

- Packaging is a discipline affecting the form and function of every element of the Constellation architecture
- When packaging discipline is well and consistently applied, it promotes effectiveness, efficiency, safety, performance, and sustainability
- NASA's Constellation program, comprising elements and missions realized over years through the cooperative effort of civil servants and contractor, will only realize global packaging efficiency if NASA implements a means to dictate and enforce a universal packaging paradigm
 - Establishment of a Packaging Working Group with adequate breadth of engagement in, and authority to influence, NASA and contractor developments, would promote the implementation of a long-term strategy that achieves optimal performance

Proportions

- Objective: explore how proportions relate to effectiveness of packaging, encompassing architecture, and end-to-end operations
- Recommend packaging proportions which address size and mass
 - Consider architectural constraints
 - Consider concept of operations
 - Consider crew capabilities

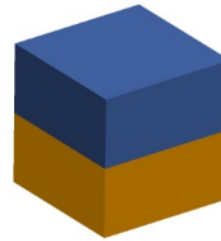
Maximum contiguous package
envelope 21 x 21 x 84
(encompasses one 95% male)



32 inch LIDS
hatch



32 inch LIDS
hatch



Standard increment
proportion
 $21 \times 21 \times 21 \sim .125$
m3



Two at $21 \times 21 \times 10.5$



32 inch LIDS
hatch

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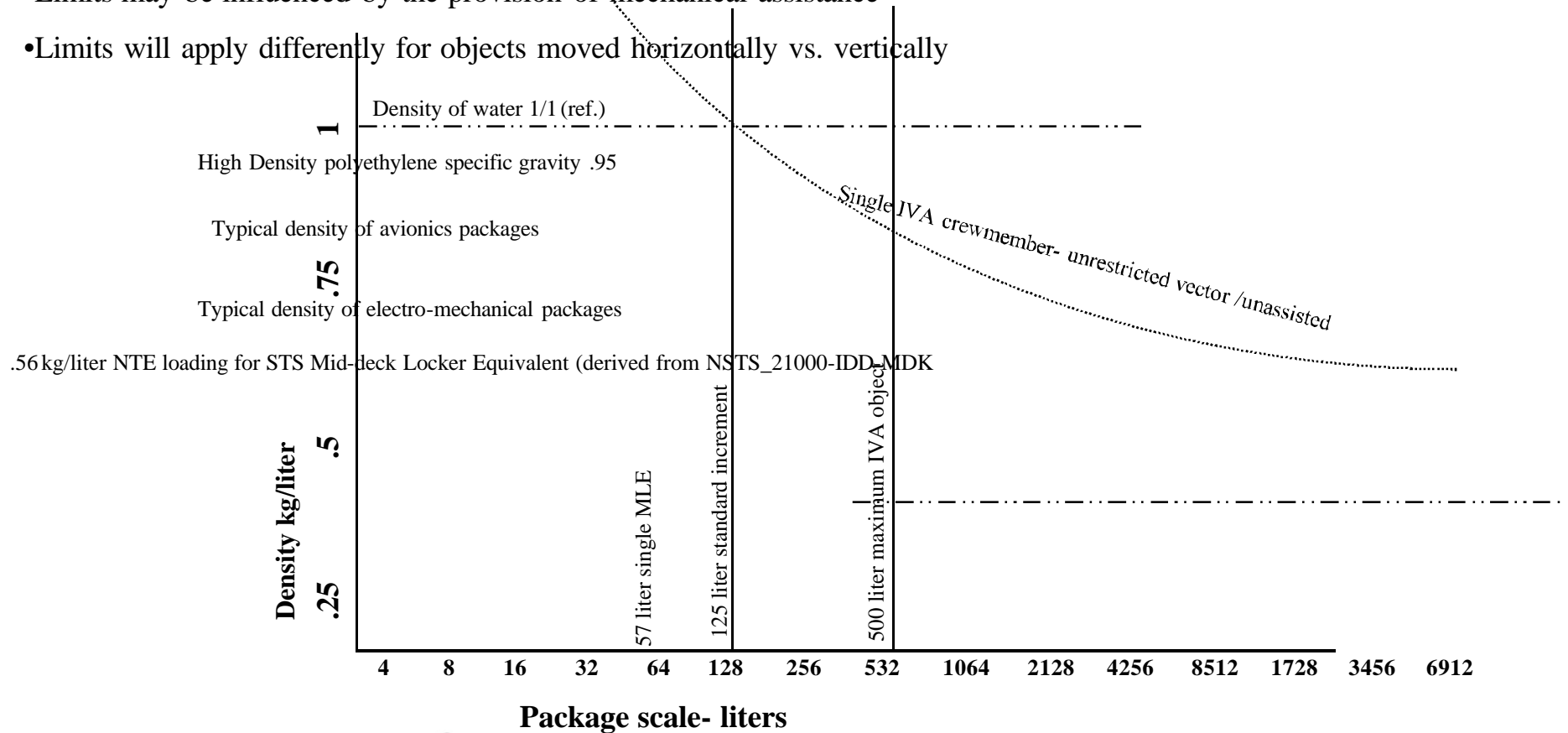
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Proportions

Density parameters should reflect package scale and crew capabilities

This notional graph represents forward work which will determine scale/density parameters for Cx packaging.

- Limits may apply differently for IVA crew operating alone, 2-crew, 3-crew, and 4-crew
- Limits will apply differently for IVA vs. EVA crewmembers
- Limits may be influenced by the provision of mechanical assistance
- Limits will apply differently for objects moved horizontally vs. vertically



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Density limits should reflect package scale and crew capabilities: cont.

- Package density and maximum weight limits must address:
 - single person, 2-person, 3-person, 4-person lift
 - Lift using mechanical assistance
 - horizontal vs. vertical translation of packages
 - 1/g influences body dynamics and balance
 - IVA vs. EVA conditions influence lifting capability
 - user/suit center of mass
 - Suit flexibility and dexterity degrades ability to grasp and lift packages
 - body weight and CG vs. package weight and CG
 - typical EVA ops will be limited to 2-person tasks, vs. IVA situations in which up to four will be available to handle out-sized packages
- Scale and density relationships are not linear or universal
 - Specific situations, applications, and handling objectives should influence limiting parameters on a case-by-case basis
- Developing a comprehensive model of 1/6 G suited and unsuited crew performance parameters will inform the development of optimal packaging design

Barrier Free Environment

- “Barrier-free”: without impediment to universal accessibility
- Cx reference architecture presents two main constraints for package transferability among elements
 - LIDS hatch
 - A 32 inch diameter hatch is currently baselined for LIDS
 - This hatch is unlikely to change, recognizing the significant investment already applied to Orion for ISS, and for the LIDS interface
 - Surface Systems element hatches
 - As embodied in NASA-developed Cx development/test prototypes and illustrated in LAT-2 conceptual briefings, the horizontally transited hatches between elements significantly exceed LIDS hatch proportions
 - Recognizing these varying constraints, the developmental Cx architecture is not “barrier free” for packaging
 - ISS lessons illustrate the down-stream penalties incurred by departing from a barrier-free global architecture

Barrier Free Environment: cont.

- ISS airlock hatch limits ORU ingress/egress to ISS pressurized volume
 - Hatch derived from STS airlock to reduce airlock DDT&E cost
- LRU-level repair and maintenance at ISS must be either EVA compatible or package must be taken into pressurized workspace (size limited by airlock)
- Many ORUs are not EVA-repairable/replaceable at a component level
- This situation has driven cost to provide external stowage platforms, to fly STS missions to pre-position external spares

Lifecycle Analysis for Packaging Data Mining

11/17/2008

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Lifecycle Analysis for Packaging Data Mining

1.0 - Introduction

A detailed understanding of mission specific implications for packaging with reference to lunar mission hardware/software, consumables, and structures/mechanisms cannot be started without using the timelines and activities appropriate to that mission. Timelines provide sequence specific information valuable as design or requirements input. The big point here is how can changes across time be leveraged to the maximum advantage. As an example, a generic short duration mission is used to cull out high level packaging issues.

2.0 - Objective

The product of this method discovers and elaborates on mission phase specific packaging topics for discussion. At the beginning of this exercise it is assumed that the generic packaging metrics are mostly defined, and the job is to find high value applications within an early stage timeline(s). The application of the packaging iteration should create better integration across tasks and mass flows within the timeline and allow integration of this value across timelines.

Lifecycle Analysis for Packaging Data Mining

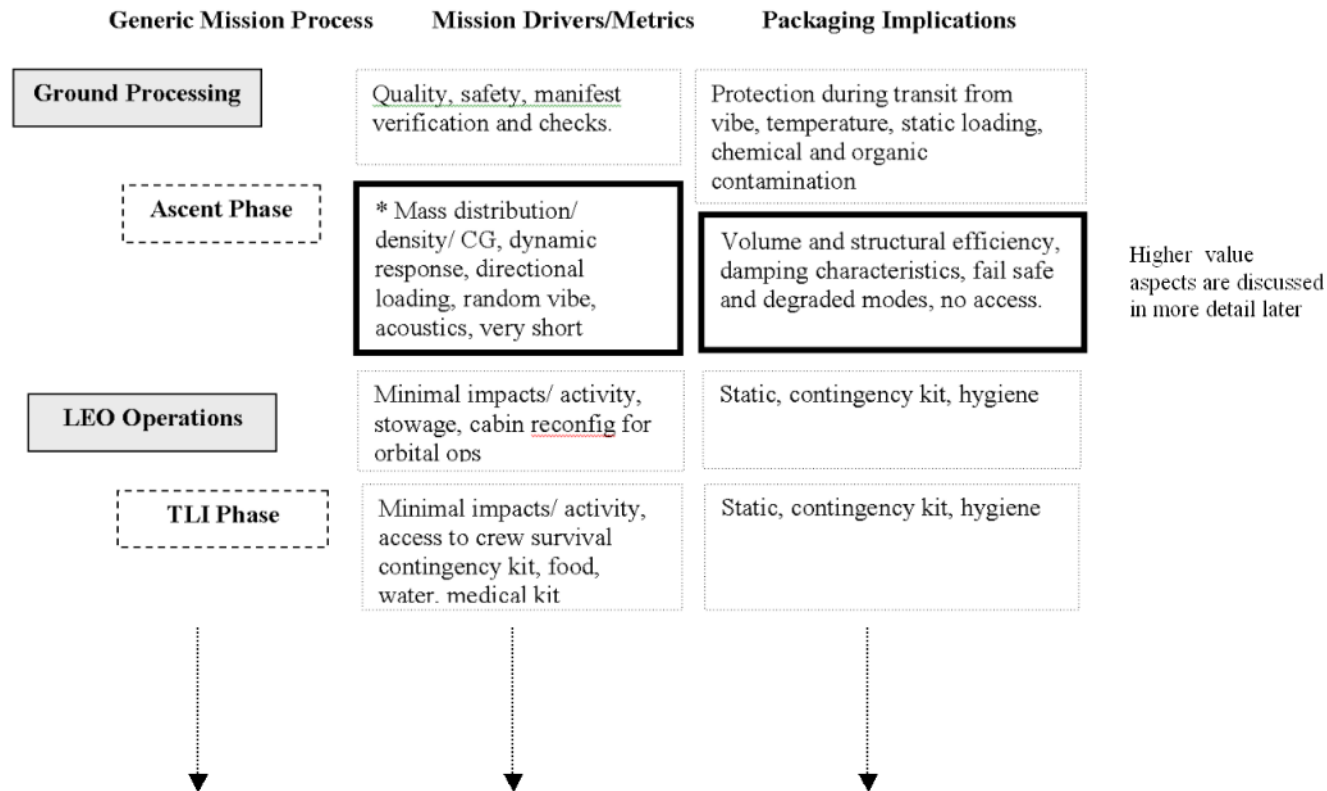
3.0 – Method

- Conduct a high level scan of a typical mission timeline
- Using preliminary packaging metrics, determine which phases of the mission are impacted to a significant degree by packaging issues.
- Expand the high value phases to draw out details that affect packaging.
- Do the above for multiple timelines.
- Compare results, optimize across missions and through time.
- Dig down into the detail of specific procedures for further improvement.

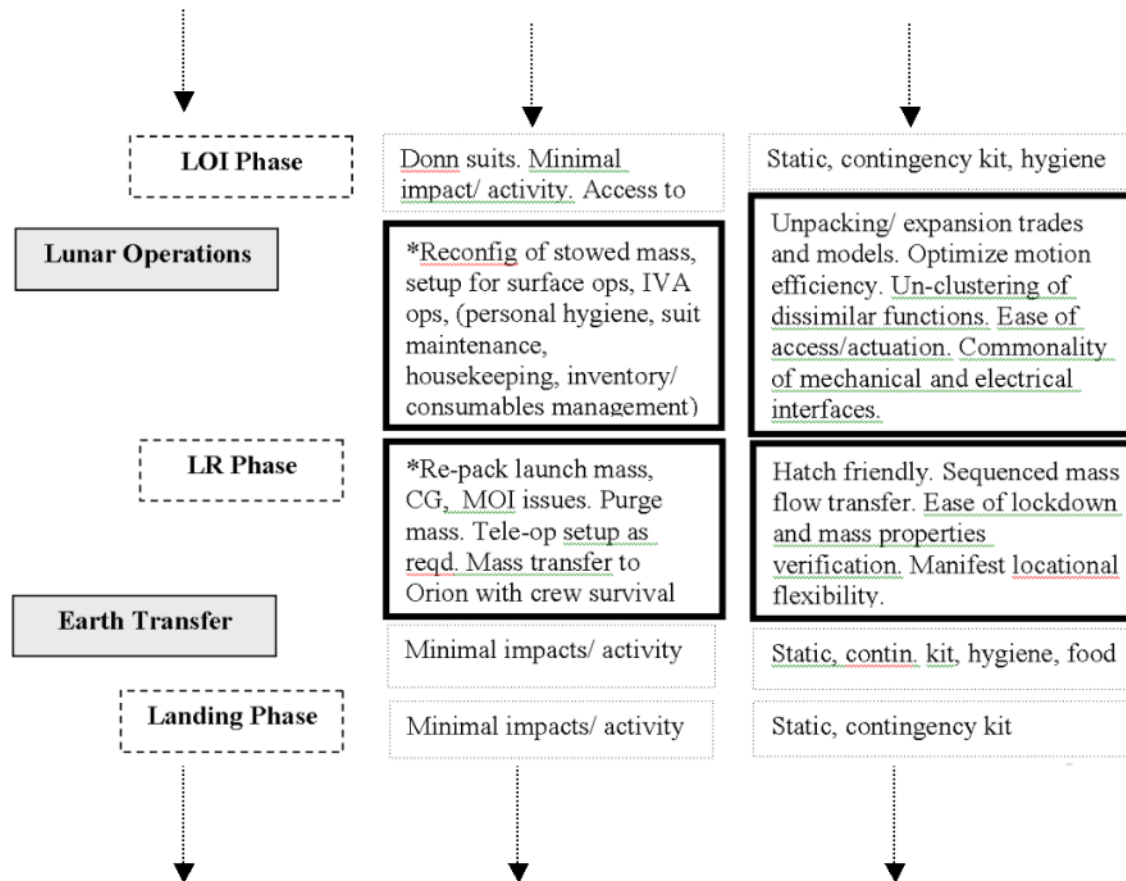
As a preliminary method, an overview of a simple short duration mission is explored through a single cycle. Each of the top level phases of this timeline are reviewed for packaging specific themes. The method is qualitative and has as output a discussion of the high value topics and relevant relationships of the packaging changes between phases for further study. Specific discussion is generated for only those phases of a timeline deemed to have high packaging value and/or activity. First, the most relevant phases are identified and then those phases are expanded upon with follow-up sheets.

Lifecycle Analysis for Packaging Data Mining

Example Lifecycle Overview



Lifecycle Analysis for Packaging Data Mining



Lifecycle Analysis for Packaging Data Mining

5 - Next Steps

This sample application demonstrates a limited overview of topics of interest and discusses potential options and ramifications. To get further traction on the subject matter, further detailed analysis of multiple mission scenarios should be processed. As these individual timelines are explored, inasmuch as they have useful resolution, they will be mined and produce potential packaging patterns.

6 - Recommendation

As suggested above, the fruit is in the detailed application. The benefit comes in using the method and establishing initial concepts and applying those to various scenarios while upgrading and optimizing based on comprehensive metrics and figures of merit. Future work should both dig deeper into individual sequence details and procedures as well as across variations and parallel processes to produce a more integrated packaging solution.

Prior to this work however should be a detailed literature search of prior applications of these methods. This will help provide firm footing and prevent some re-invention.

Food and Waste Packaging

Our study addresses nutritional packaging from the perspective that food is but a means to package nutrition. Our approach combines nutritional and hydration needs with means to manage metabolic waste to identify a systemic approach which minimizes mass and volume.

Culinary considerations aside, we explored a minimalist approach to supplying nutrition to the crew in a manner than minimizes packaging overhead

Nevertheless, our recommendations do not preclude additional food options, and themselves do preserve options for menu diversity

End-to-End Packaging for Human Metabolic Support

- Comprises Food/Drink and Waste Packaging from Launch to Disposal
- Food/Drink Packaging
 - Transport
 - Storage
 - Preparation
 - Consumption
 - Cleanup
- Metabolic Waste Packaging
 - Collection
 - Food packaging waste
 - Wet food/fecal waste and used wipes
 - Urine and waste drink
 - Respiration/perspiration water
 - Waste Treatment
 - Potable water recovery from wastewater
 - Wet solid waste bio-stabilization
 - Storage and Disposal

Human Metabolic Model and Packaging Implications

- NASA Model (pounds per person per day, active 30s-something American males; conservatively high for mixed-gender crews)

• Input	
• Food/drink water	7.0
• Breathing oxygen	1.8
• Food/drink solids	1.2
• Total Metabolic Input	10.0
• Output	
• Respiration/perspiration water	4.2
• Urine water	3.2
• Carbon dioxide	2.2
• Feces	0.3
• Urine solids	0.1
• Total Metabolic Output	10.0

- Packaging Implications
 - Food/drink water 70% of input; respiration/perspiration/urine water 74% of output
 - Minimizing penalties for metabolic support requires recovery of all food/drink water from respiration/perspiration/urine, and use of only dry food/drink solids from Earth

Dehydrated Food/Drink/Packaging Performance

- Nutritional Performance
 - Great variety of protein/fruit/vegetable/grain/drink items are available
 - Rehydrated quality is as good or better than thawed cooked frozen food
 - Shelf life unopened is 5-30 years with no air exposure (hermetic packaging)
 - Shelf life opened and covered with air exposure is about nine months
- Mass Performance
 - Wet foods average about eighty percent water by mass
 - So dehydrated food weighs about one-fifth as much as wet food
- Volume Performance
 - Dehydrated food density w/o size reduction is about twice that of wet food
 - Density with size reduction to powder is about three times that of wet food
- Packaging Performance
 - Gallon bags can hold about 4.4 lbm of food powder, corresponding to 22 lbm of wet food
 - Gallon-sized resealable metallized (hermetic) plastic bags weigh about 0.1 lbm
 - So dehydrated food packaging performance is 220 lbm of wet food per lbm of bag

Food/Drink Rehydrated with Imported Potable Water

- If potable water recovery from wastewater is not part of the MFHE, potable water for food/drink rehydration must be imported from the Earth to the Moon
- Water Packaging Performance
 - ISS Contingency Water Carrier (CWC) is flight-qualified to transport potable water
 - Each CWC is 18" D x 24" L, weighs 2.95 lbm, and holds 95 lbm of water
 - Mass performance is 32 pounds of water per pound of CWC
 - Commercial nautical water bags have similar mass performance
- Daily average mass penalty per person for water supply without MFHE potable water recovery from wastewater is 7.0 lbm, plus 0.22 lbm of packaging
- Rehydrated Food Packaging Performance
 - 4.4 lbm of dehydrated food/drink can be transported in a 0.1 lbm bag
 - 17.6 lbm of potable water required to rehydrate 4.4 lbm of food/drink powder
 - 0.55 lbm of CWC required to transport 17.6 lbm of potable water
 - So 0.65 lbm of packaging required to transport 22.0 lbm of rehydrated food/drink
 - Overall performance is 34 pounds of rehydrated food/drink per pound of packaging without MFHE potable water recovery from wastewater

Food/Drink Management Packaging

- Legacy space mission food management had to be microgravity compatible; meant individual serving containers with very high packaging penalties, especially mass
- Lunar surface gravity allows use of gravity-enabled methods of food/drink storage, preparation, consumption, and cleanup (The “Gravity Galley”)
- Gravity Galley Concept
 - Transport of all food/drink as dehydrated solids in standard bulk containers
 - Gallon-sized resealable metallized plastic bags, vacuum-packed
 - Shelf life five years minimum; open life nine months covered
 - Storage of food/drink as dehydrated solids in standard bulk containers
 - Gallon-sized slide-out trays, one for each food/drink type
 - Wall of close-packed trays minimizes storage volume
 - Each tray refilled from one food transport bag
 - Transfer of individual portions from storage trays to consumption devices
 - Each crewmember has personal drink bottle, wet food tray, and utensils
 - Each crewmember responsible for cleanup of own consumption devices
 - Rehydration of dry food/drink with hot or cold potable water

Waste Management Packaging

- Waste Collection Concepts
 - Food packaging waste
 - Empty food-transport bags stored in dedicated container
 - Bags reused for wet solid waste collection and storage
 - Wet food/fecal waste and used wipes
 - Collected and stored in empty food-transport bags
 - Food bags compatible with gravity-enabled dry toilet, collapsible when not in use.
 - Urine and waste drink
 - Legacy space mission urine collection had to be microgravity compatible
 - Lunar surface gravity allows use of gravity-enabled unisex urinal
 - Waste drink collected in urinal for treatment with urine
 - Perspiration/respiration water vapor
 - Legacy space mission water vapor collection had to be microgravity compatible
 - Lunar surface gravity allows use of hydrophobic-coated condensing heat exchanger (no biofilm growth) and gravity-enabled condensate-air separator ("knock-out drum")

Waste Management Packaging - Continued

- Waste Treatment Concepts
 - Potable water recovery from wastewater
 - Required to minimize human metabolic support logistics penalties
 - Metabolic water vapor condensate “polished” by multifiltration (flight-qualified)
 - Urine and waste drink treated by gravity-enabled vapor compression distillation (Smaller and more efficient than ISS flight-qualified microgravity-compatible version)
 - Wet solid waste bio-stabilization
 - Feces, wipes, and waste food can be bio-stabilized with small amounts of commercially-available biocide/dessicant/deodorant powder mixes
- Waste Storage and Disposal
 - Treated wet solid waste contained in sealed food-transport bags (reuse)
 - Dry solid waste contained in dry material transport bags (reuse)

Metrics

- Its comfortable to address familiar metrics like mass and volume, but assessing packaging effectiveness requires recognition of additional metrics
 - Surface area per unit volume
 - Robotic operability
 - Residual value
 - Crew Time
 - Safety
 - Necessity

Metrics (cont.)

- Part of the packaging discipline must be identification of application-specific metrics and assessment of packaging life-cycle to balance the metrics in a manner consistent with the application

Example: Parachute packaging vs. Sleeping Bag packaging

- Similar size, weight, materials, and compaction factor
- Both can save your life in critical situations. But nobody spends hours packing their sleeping bag, and nobody would jump with a chute that was stuffed into a bag by the hand-full
- These applications illustrate widely disparate requirements for packing and deployment speed and orderliness

Analogs

- We've explored several of many possible analogs which can inform the development of an effectively integrated system of Constellation elements, vehicles, packaging, and packaging contents

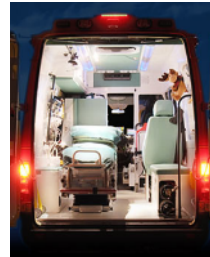
- Characteristics of valid analogs include applications with:
 - numerous contained items aboard...
 - vehicles operating in hostile conditions...
 - time-sensitive responsiveness requirements...
 - and performance critical situations
- Lessons available from analogs include:
 - Tiered packaging benefits organization and integrity of contents
 - The effectiveness of a packaging solution must be mirrored in the configuration of the hosting environment

Examples of analogs



- Bass boats

- Myriad contents
- Clean-deck
- Rough-ride
- Minimum available volume and weight capacity



- Ambulances

- Tight quarters
- Time-critical access
- Rough ride

- Med-evac Aircraft

- Mass sensitive
- Time sensitive access
- Accuracy and orderliness
- Hazardous contents (sharps)

- Gadget Bags

- Transparent to infusion of maturing technological contents
- Time-critical access
- Shock and contamination sensitive
- Lots of variety in a small package
- portable



- Fire Trucks

- Time sensitive access and deployment
- Rough ride
- Life-critical missions
- Orderliness



These analogs illustrate how packaging and vehicle may be one-in-the-same, how sometimes the best package is no package, how human scale, contents details, and operational scenarios combine to influence optimal packaging

Energy Packaging

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Energy Packaging

1.0 - Introduction

Energy as used for purposes other than propulsion covers a significant portion of mission systems and activities. The power requirements discussed here will be limited to electrical systems, although they may be driving fluids or chemical processes with various means. Energy packaging is largely tied to batteries and fuel cells or possibly fission devices at the extreme. To some degree it extends into transmission of power.

2.0 - Objective

The purpose of this exercise is to drive out energy packaging metrics and design parameters. These factors are relevant when discussing energy packaging as a component of the larger packaging scheme. Proper energy packaging is closely tied to modularity, but is a leveraged asset because of the universal need for energy in all systems and additionally for the importance of a redundancy of energy sources.

Energy Packaging

3.0 – Method

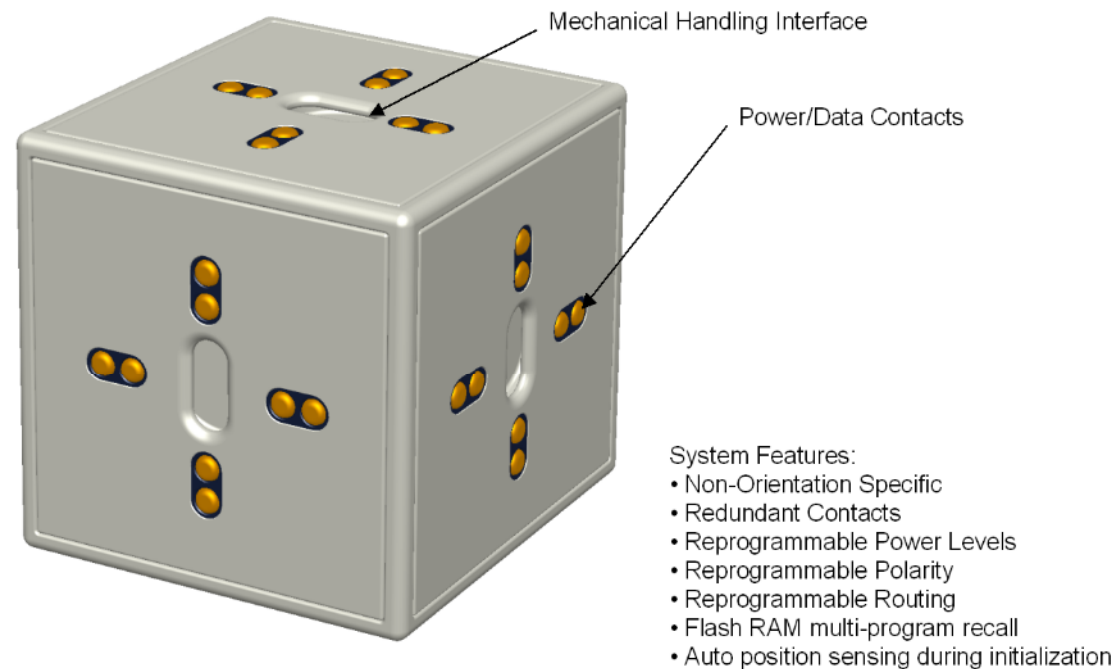
§ Propose a generic battery packaging design/scheme

§ Walk through the applicable hardware and look for fits while proposing mods, upgrades, and changes to user hardware that work to create a more efficient packaging concept.

This exercise will start with a generic description of a lowest simplicity flexible battery system. The system incorporates basic scale-ability, re-programmability, redundancy, heat rejection, and others.

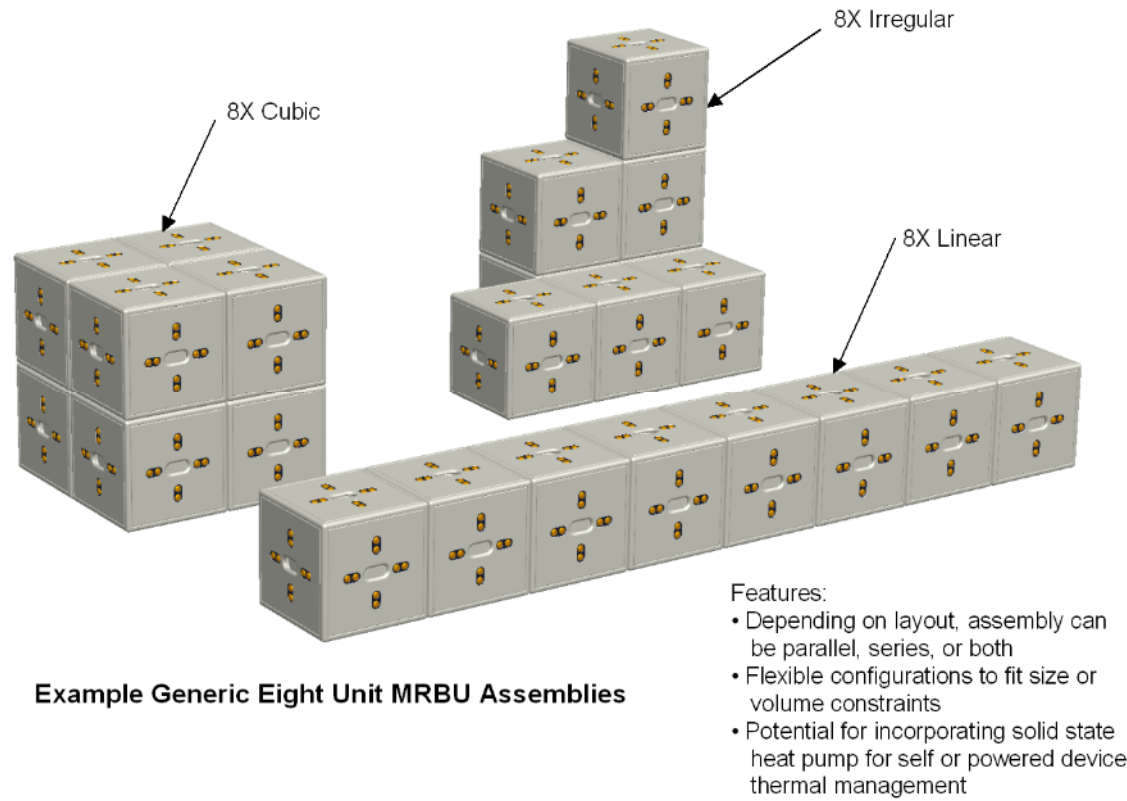
Following that is a listing some major subsystems for brainstorming potential applications. For each of those it will expand on the characteristics that a power storage component must have to support that system. Finally, natural commonality and driven commonality will be listed that appears to the standard set of packaging incentives, which include safety, mass reduction, modularity, cost minimization, and to some level risk mitigation.

Energy Packaging



Example Generic 2x2x2" Multi-Purpose Re-programmable Battery Unit (MRBU)

Energy Packaging



Energy Packaging

Usage Brainstorming Diagram

IVA

suit related electronics
power
air pump
communication
data
tools
DVD, CD, flash players
cameras
personal computers and electronic devices
crew survival equipment

Possible battery backup for lower torso pressure bladder.

Smaller modular battery units.

Most likely COTS batteries because of wasteful development costs.

Most likely COTS batteries because of wasteful development costs.

Most likely COTS batteries because of wasteful development costs.

Modular battery system for redundancy and reconfigurability

EVA

suit related electronics
power
fuel cell, hydrogen/oxygen, fans, pumps, advanced features
support and so must work always.

PLSS battery systems should be intimate to the packaging design philosophies. They are critical life



Energy Packaging

5.0 – Recommendation

- § Study current commercial/defense approaches to power packaging.
- § Screen for efficient approaches or novel concepts.
- § Incorporate best ideas into power aspect of the packaging scheme.
- § Apply to Orion static designs, time changing/morphing systems and contingency scenarios.

A study of the state of the art of battery sizing with emphasis on the commercial electronics market may reveal patterns of battery design patterns that can be converted to design recommendations or requirements. Study of the existing configurations will reveal classes of drivers that will likely shape the subclasses of modular systems of batteries required for the Orion mission requirements. The subclasses can then be broken down into logical sizing and form factors for the expected end uses, contingency scenarios and potential forward reconfigurations on site.

Lunar Sample Return Packaging

- We've explored Lunar Sample Return packaging as a specifically challenging application with near-term implications for Orion and Altair development
- Sample return presents a particularly complex set of requirements, environments, transportation and usage parameters
- Our approach seeks to take advantage of Apollo experience and address requirements developed since Apollo

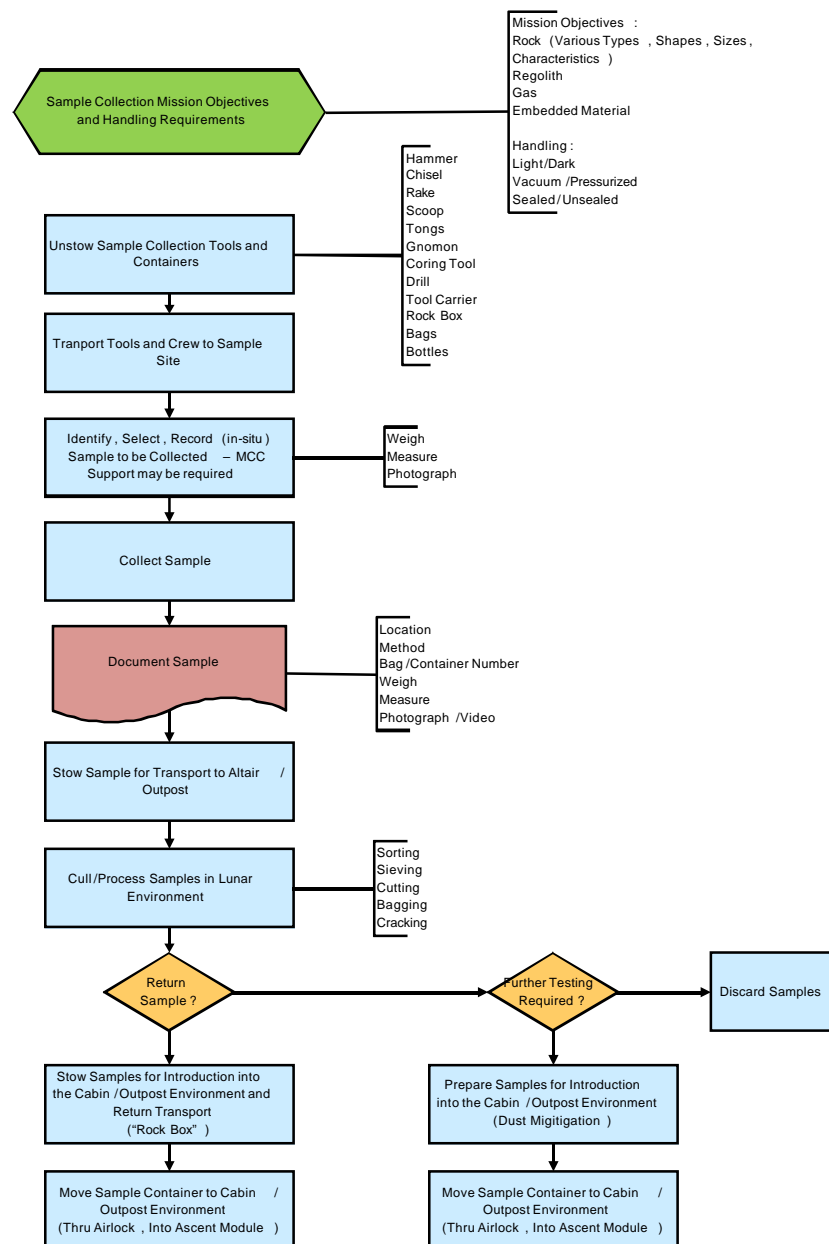
Apollo vs Constellation

- Apollo 17 transported 45.6 kg of tools and containers to the surface, to return 110.5 kg of sample material. See Table 1 for Apollo summary sample, tool, and container weights.
- Altair plans to return 100 kg of material but has only allocated 7.4 kg of sample return containers. Each (of two) containers is approximately 21x18x11 inches.
- There appears to be conflict between Altair and CEV resource allocations for accommodation of sample recovery packaging and sample mass

Mission	Sample Return (kg)	Tools & Container (kg)	Sample / Tool-Container Ratio
Apollo 11	21.6	22.8	0.95/1
Apollo 12	34.3	29.1	1.18/1
Apollo 14	42.3	34.1	1.24/1
Apollo 15	77.3	50.3	1.54/1
Apollo 16	95.7	53.0	1.81/1
Apollo 17	110.5	45.7	2.42/1
Altair (provisional requirement)	200	7.4	.037/1

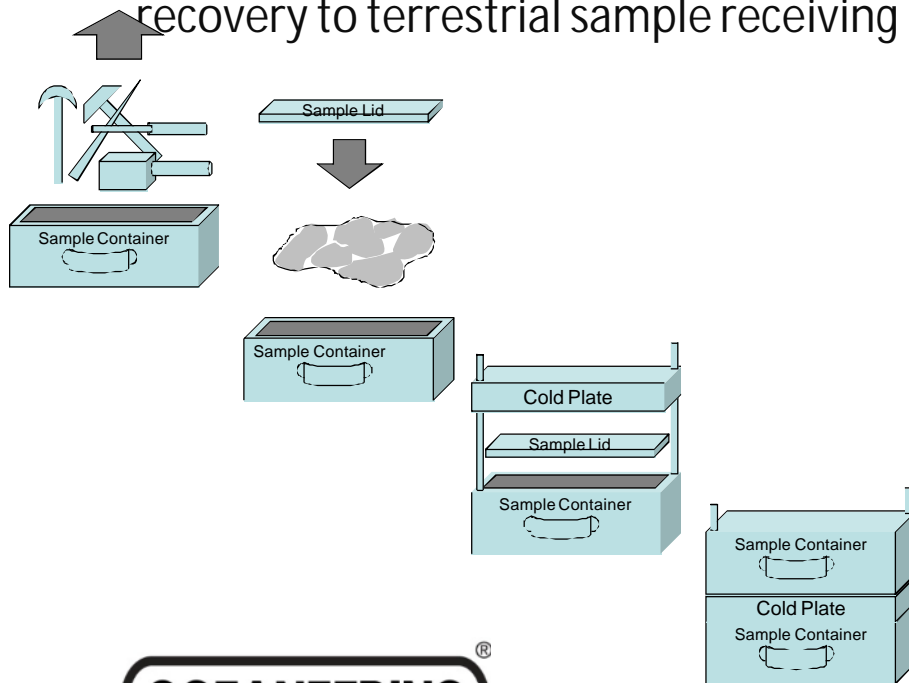
The Sample Return Mission Sequence

- An end-to-end sequence is presented which reveals the many environments and transitions inherent in this application
- Recurring missions to a common outpost distinguishes Constellation operations from Apollo missions
- Ability to recover environmentally Thermally-controlled regolith containing volatiles presents challenging requirements affecting package configuration, availability of services in transport vehicles, timelines, etc.
- Ability to do in-situ sample vetting and culling influences packaging functions relative to the surface architecture



Representative concept

- Delivery and return operations apply the packaging to advantage
 - Delivery phase may utilize package to contain sampling tools and supplies
 - Lunar surface operations apply packaging to collect prepared samples for recovery to Earth
 - Return phase uses packaging to transport samples from surface assets to Altair ascent stage, transfer to CEV, and endure return flight and support post-landing recovery to terrestrial sample receiving laboratories



- Sample packaging development must correlate with surface asset development to achieve a seamless and efficient means to delivery packaging, apply packaging in varying environments, process and protect samples, organize samples, and ensure intact return
- Sample recovery rate requirements are intended to exceed Apollo capabilities

Relationships between lunar sample recovery packaging and Cx transportation and surface elements

- Sample return packaging may be delivered as :
 - Unpressurized cargo item aboard a sortie lander which is applied on the surface and returned on the same mission via the Altair ascent stage and transfer to the CEV
 - Pressurized cargo aboard a sortie lander which is deployed via the airlock, applied on the surface, and replaced via the airlock for Altair/CEV transport to Earth
 - Cargo delivered aboard a pressurized or unpressurized logistics carrier servicing an outpost site
 - In the case of outpost operations, sample return packaging may remain on the surface in anticipation of recovery on a future mission
- On-the-surface operations demand EVA , EVR and Small Pressurized Rover compatibility
- Potential to apply IVA crew in in-situ vetting and culling of samples may present additional compatibility issues for packaging and interface requirements for pressurized elements
 - CONCEPT: Interactive IVA and EVA sample handling may be facilitated by an unpressurized workstation which is jointly accessible by EVA crew and by IVA crew operating via glove-box-like features embedded in the pressure vessel of a habitat
 - Eliminating the need to transfer lunar samples into the habitat offers the advantage of executing all sample preparation without mutually exposing samples and habitat
- Incorporation of in-situ sample-processing capability influences the development of the sample containment packaging AND the assets involved in collecting, transporting samples on the surface, assaying, cataloging, protecting, and returning samples and containers to Earth

Architectural Simulations Concepts

- OSS is unaware of simulation capabilities which enable rapid assessment of the influence of architecture-level variables on the effectiveness of the Constellation as a holistic system
- Popular games like “Civilization” engage the public in simulations which enable operators to make decisions and realize consequences at an enterprise level
- Similar public-engaged simulations based on controlled variations of the Constellation architecture might offer insight into performance potentials inherent in variable architecture and identify operational strategies and relationships to architectural variables which could inform the development and operation of an inherently sustainable lunar exploration enterprise
- Packaging scale, vehicle capacities, interface constraints, and other variables could be “tweaked” over time and in response to simulation results to “test-fly” varying architectural parameters and determine their influence on inherent performance potential
- The development and management of such a simulation could involve a collaboration between NASA and the computer game industry
- Engaging the public in such simulations could improve recognition of the challenges of lunar exploration while developing an experienced cadre of next generation explorers, exploration system developers and operators.